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Residential heat pumps in the future Danish energy system

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Residential heat pumps in the future Danish energy system

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Elements of future Danish energy system

- Wind power
- District heating
- Residential heat pumps, biomass boilers and solar heating
- Heat savings in buildings
- Demolition of existing and construction of energy-efficient buildings

Residential heat pumps in the previous studies

- Oil and natural gas boilers are switching to residential HPs in 2025 (Münster et al. 2012)
- Expansion of district heating around cities and towns and residential HPs (Lund et al., 2010, Möller and Lund, 2010)
- Expansion of district heating based on biomass and large HPs and residential HPs, solar heating and biomass boilers (IDA's Climate Plan 2009)
- District heating, solar heating and residential heat pumps in Aalborg and Frederikshavn (Østergaard et al., 2010 and Østergaard, 2012)

Benefits of using residential heat pumps

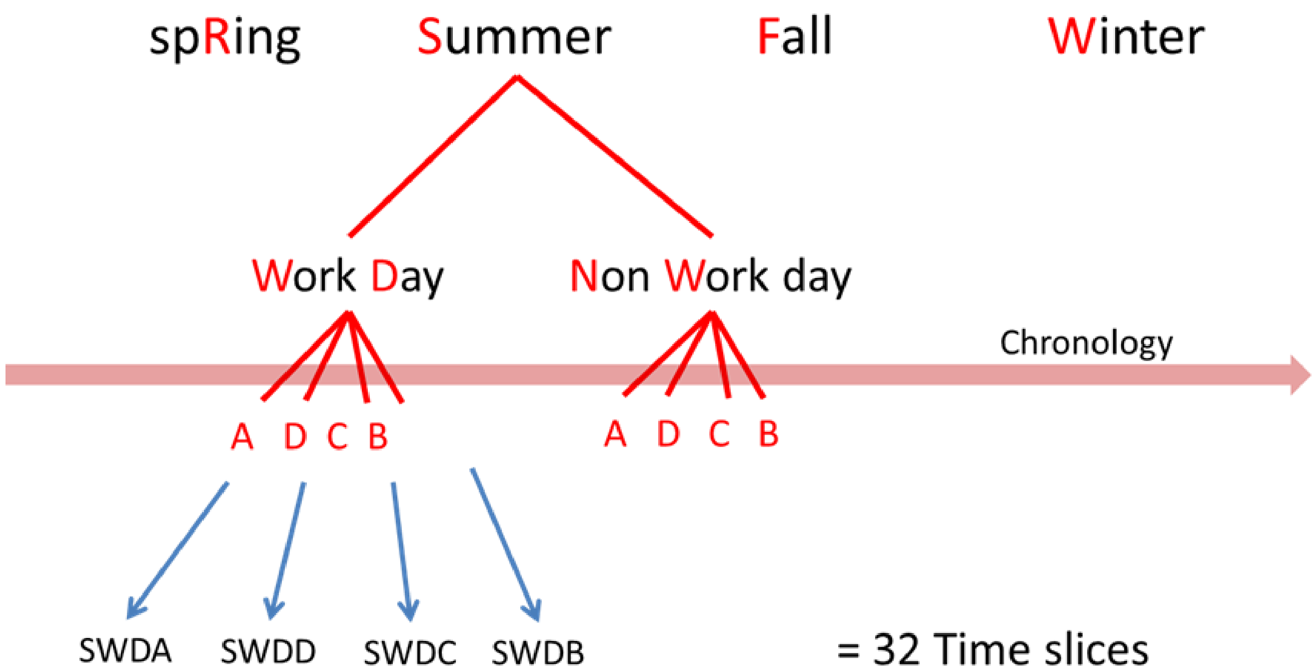
- Contribute to the integration of wind power and PVs – provide flexibility and reduce excess power production

- Reducing fuel consumption, CO_2 emissions and total system costs

- Favoured in high health impact areas

TIMES-DTU – time definition

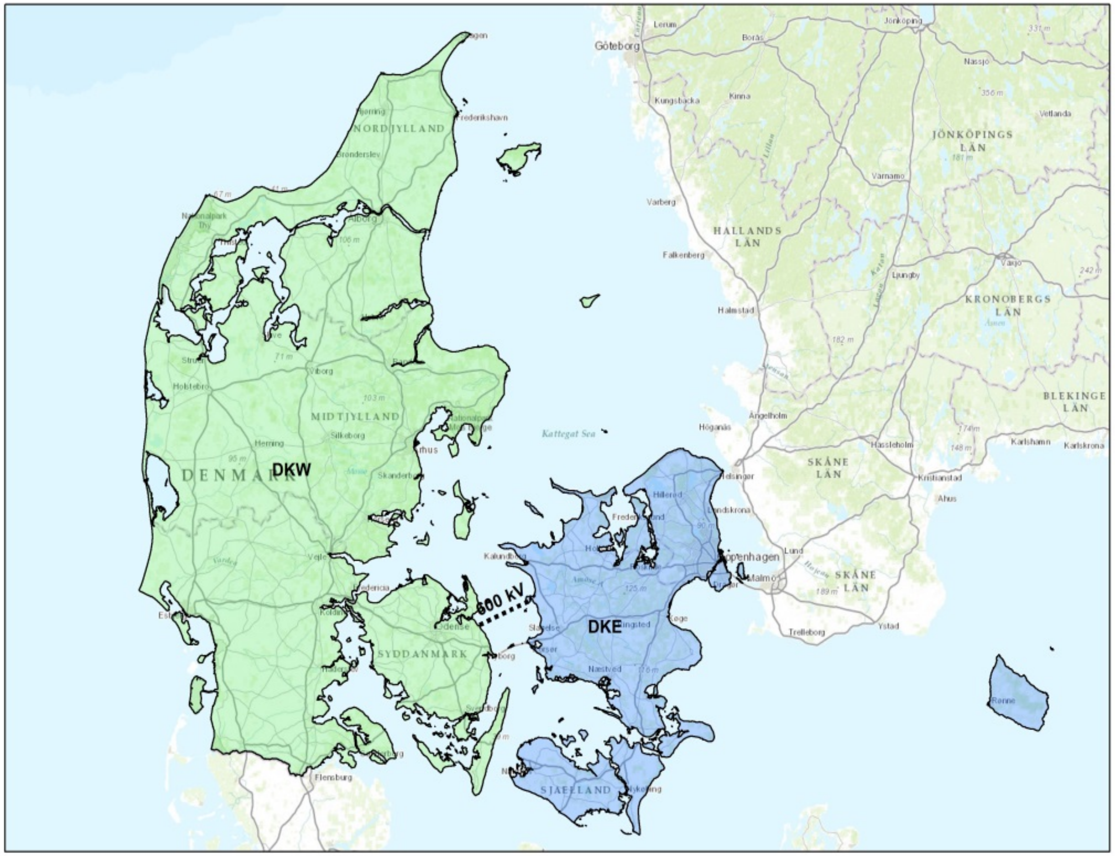
- No chronological values
- 32 time-slices and 10 model-years



Time period	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Start year	2010	2011	2014	2018	2023	2028	2033	2038	2043	2048
End year	2010	2013	2017	2022	2027	2032	2037	2042	2047	2052
Length (years)	1	3	4	5	5	5	5	5	5	5
Representative year	2010	2012	2015	2020	2025	2030	2035	2040	2045	2050

TIMES-DTU – geographical definition

- Two regions – East and West Denmark
- Subdivisions into Central, Decentral and Individual



TIMES-DTU – geographical definition

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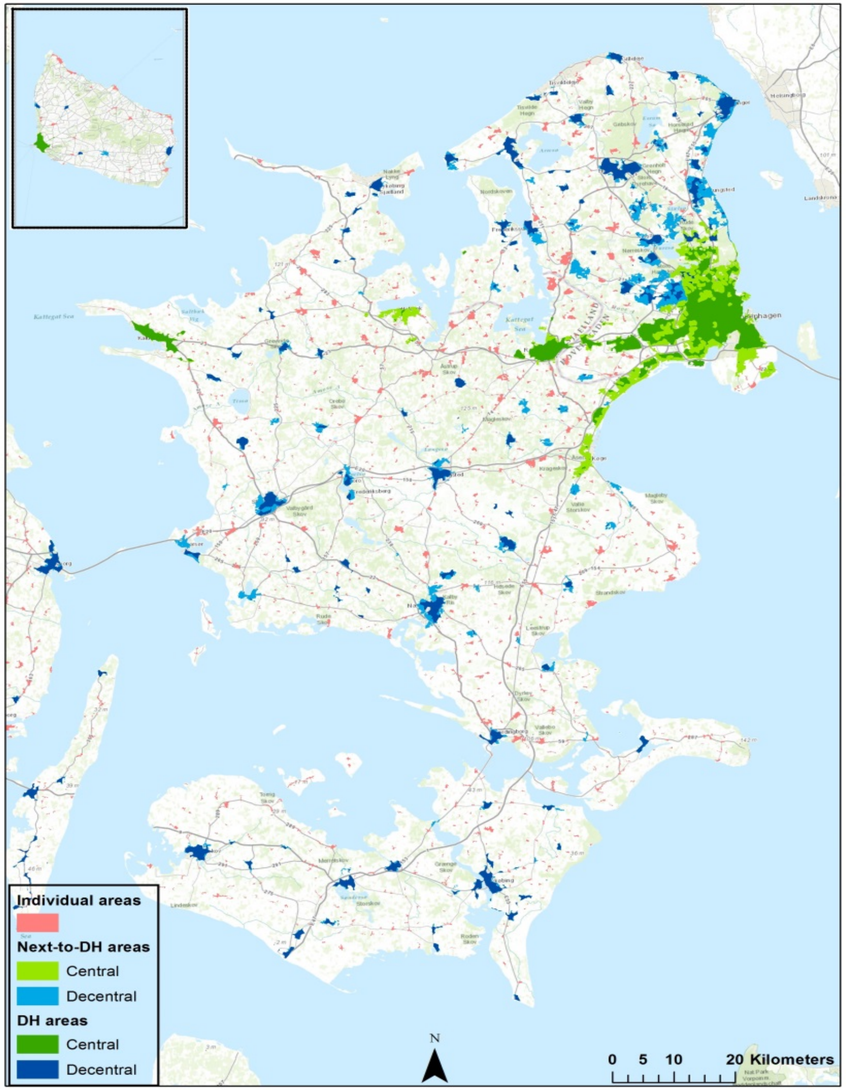
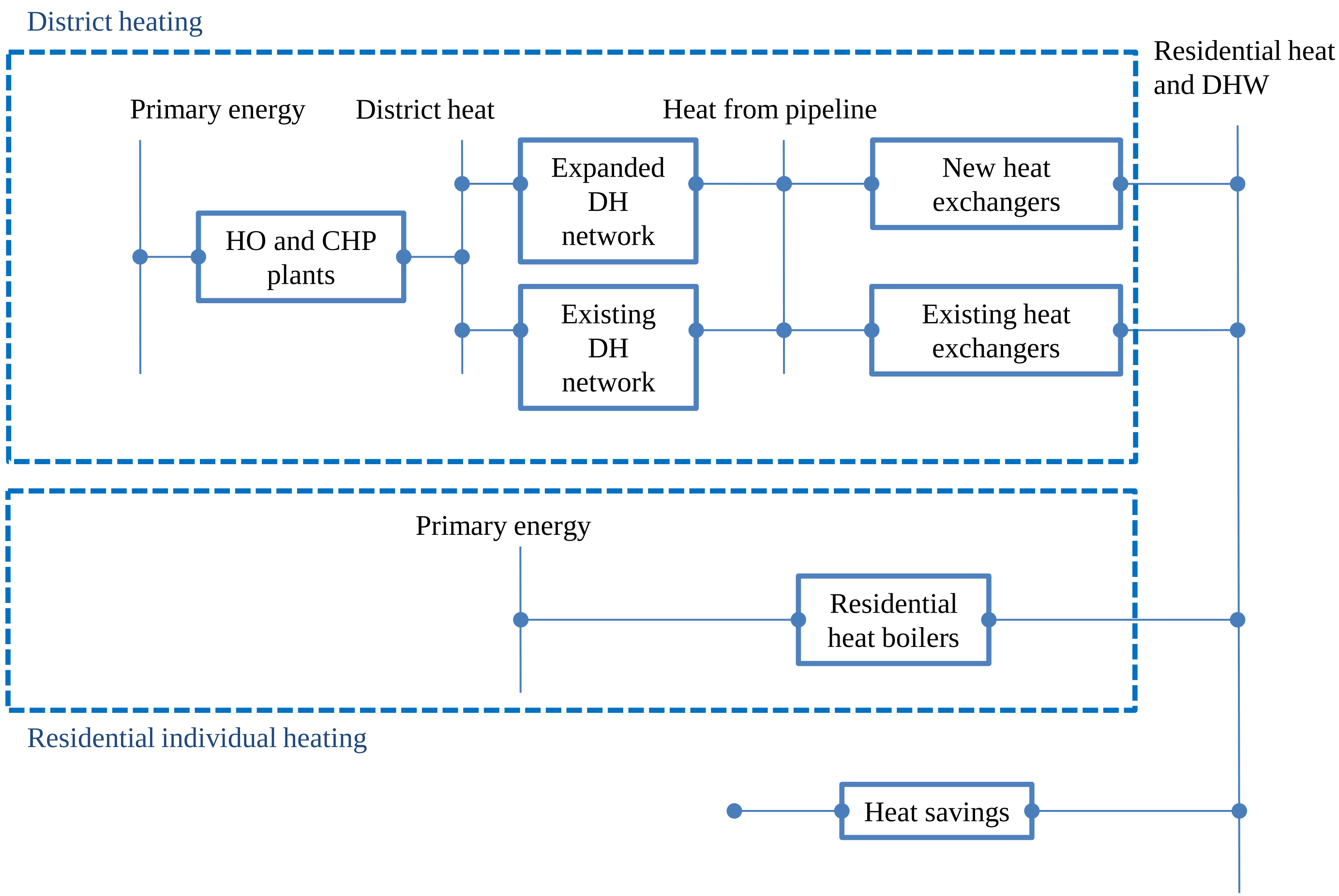


TIMES-DTU model – residential buildings

- Region – DKE and DKW
- Construction period – before 1972, after 1972 and new buildings
- Location relative to existing district heating areas – Central, Decentral and Individual
- Building use – Single-family and Multi-family
- Heat savings, construction, demolition

Supply of heat and DHW in TIMES-DTU



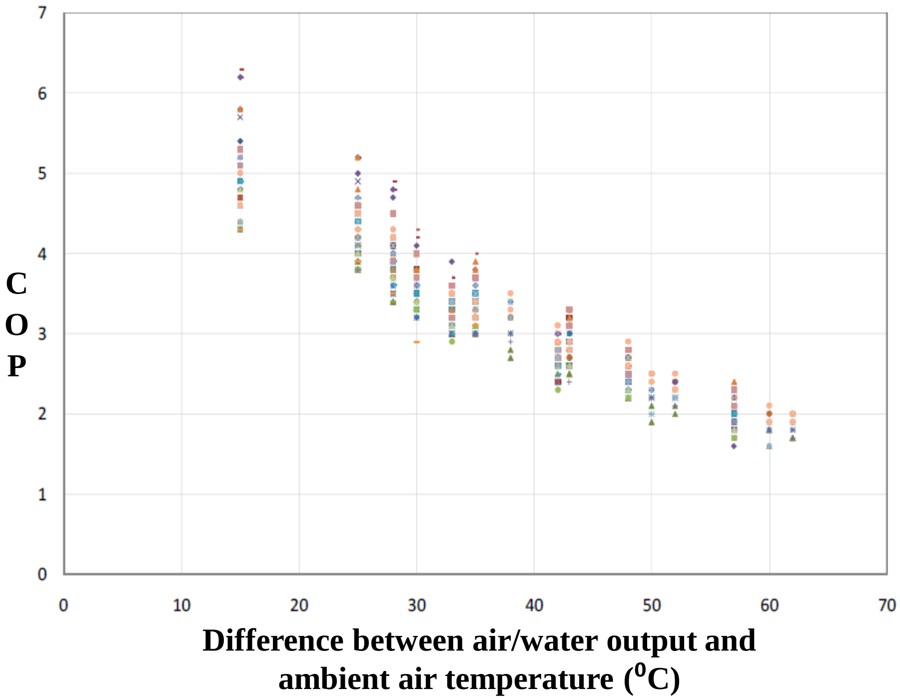
TIMES-DTU model – Modelling of residential heat pumps

- Three types of residential HPs are modelled
- **Variable COPs**
- **Spatial constraints**
- Other techno-economic parameters

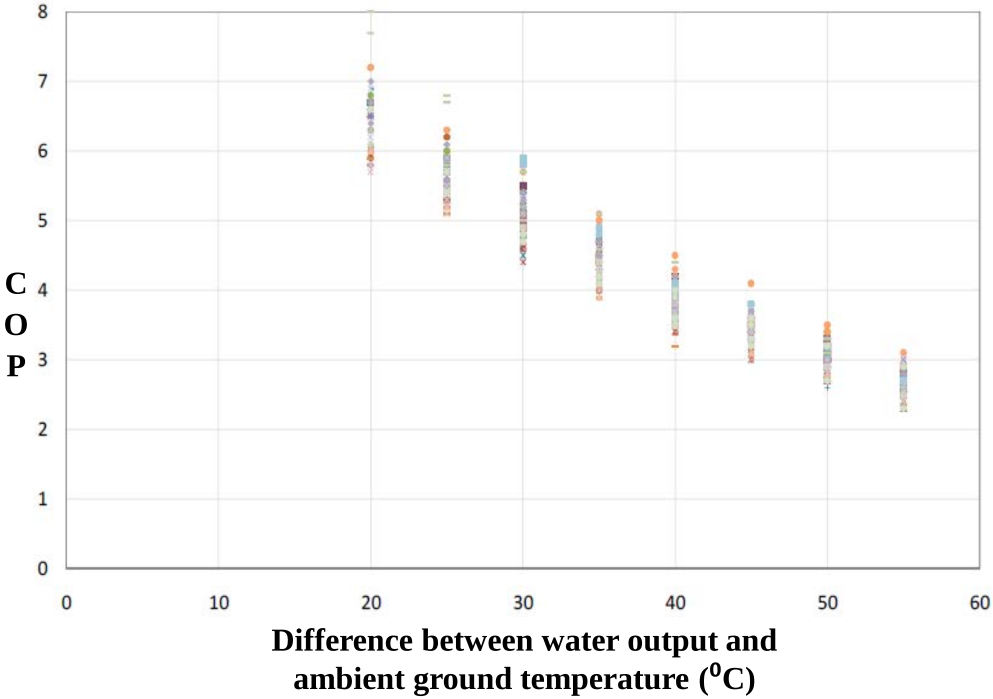
		Single-family buildings					Multi-family buildings				
Type	Year	Inv. c. $\left(\frac{MDKK}{MW}\right)$	Lifetime (years)	Fix. O&M c. $\left(\frac{MDKK}{MW \cdot year}\right)$	Var. O&M c. $\left(\frac{MDKK}{PJ}\right)$	Availability factor	Inv. c. $\left(\frac{MDKK}{MW}\right)$	Lifetime (years)	Fix. O&M c. $\left(\frac{MDKK}{MW \cdot year}\right)$	Var. O&M c. $\left(\frac{MDKK}{PJ}\right)$	Availability factor
Air-to-air	2015	4.02	20	0.06	0	0.12	4.02	20	0.06	0	0.12
	2020	3.87					3.87				
	2030	3.58					3.58				
	2050	3.43					3.43				
Air-to-water	2015	9.69	20	0.10	0	0.20	7.45	20	0.01	0	0.20
	2020	8.94					7.45				
	2030	8.94					6.71				
	2050	8.20					6.71				
Brine-to-water	2015	12.67	30	0.10	0	0.20	8.20	30	0.01	0	0.20
	2020	11.92					8.20				
	2030	11.18					7.45				
	2050	10.43					6.71				

Temperature-dependant COP

Air-source heat pumps

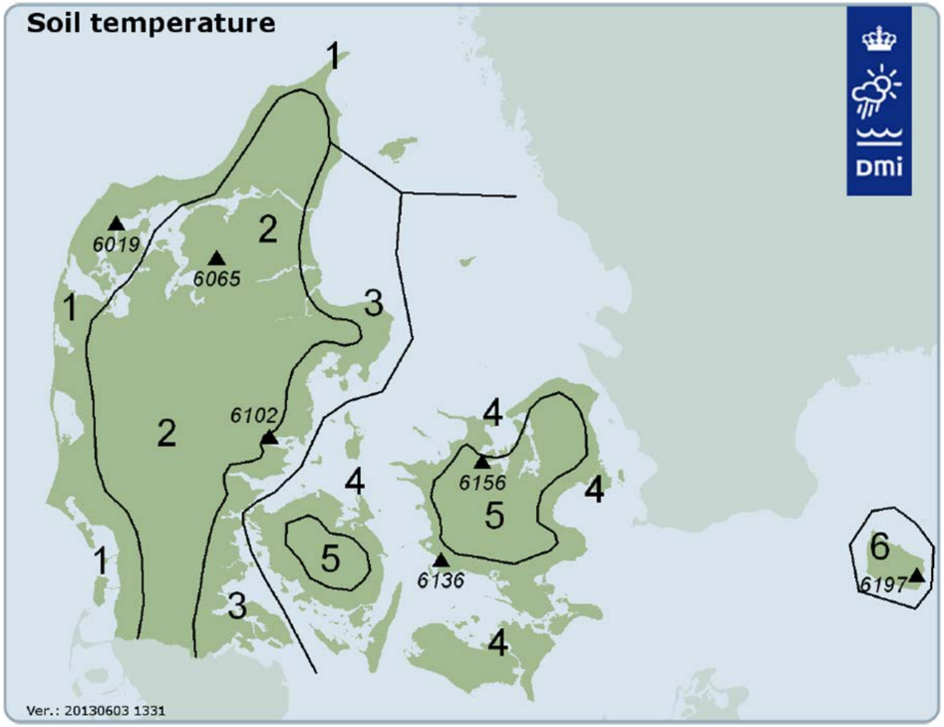


Ground-source heat pumps

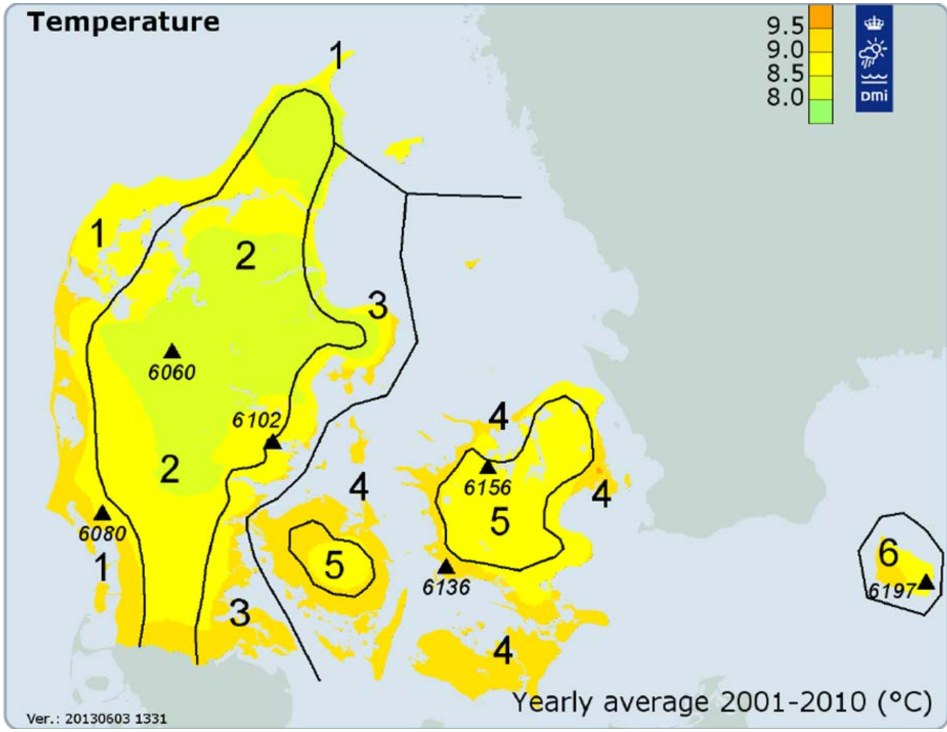


COPs are expressed as a linear function of a temperature difference between air/water output and ambient temperature

Temperature regions

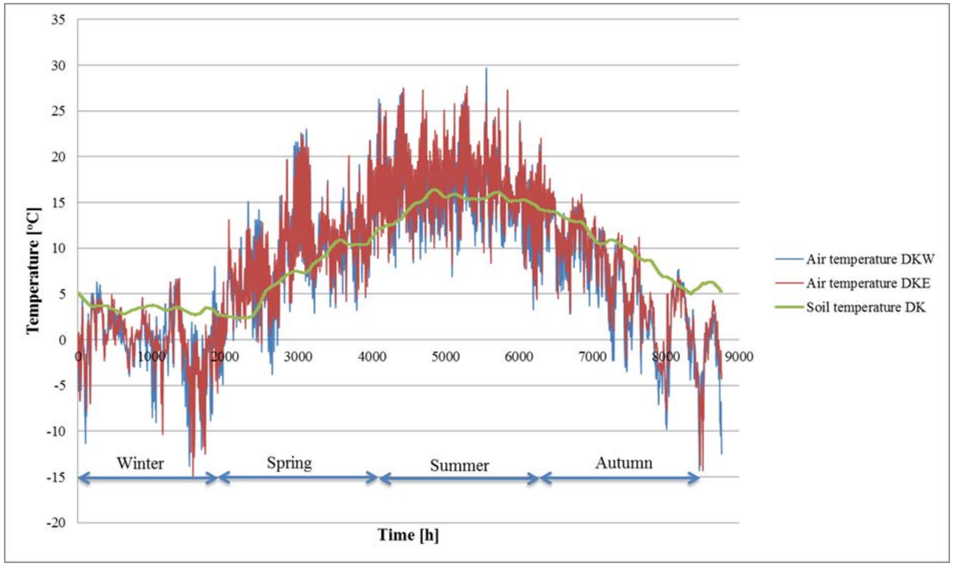


Soil temperature regions in Denmark

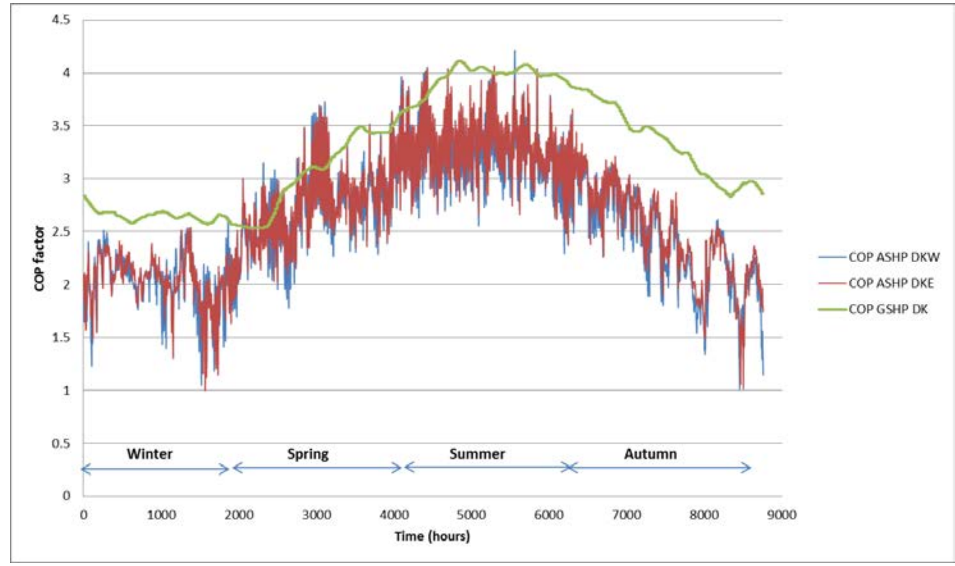


Air temperature regions in Denmark

Temperatures and calculated COPs



Hourly changes of air and soil temperatures



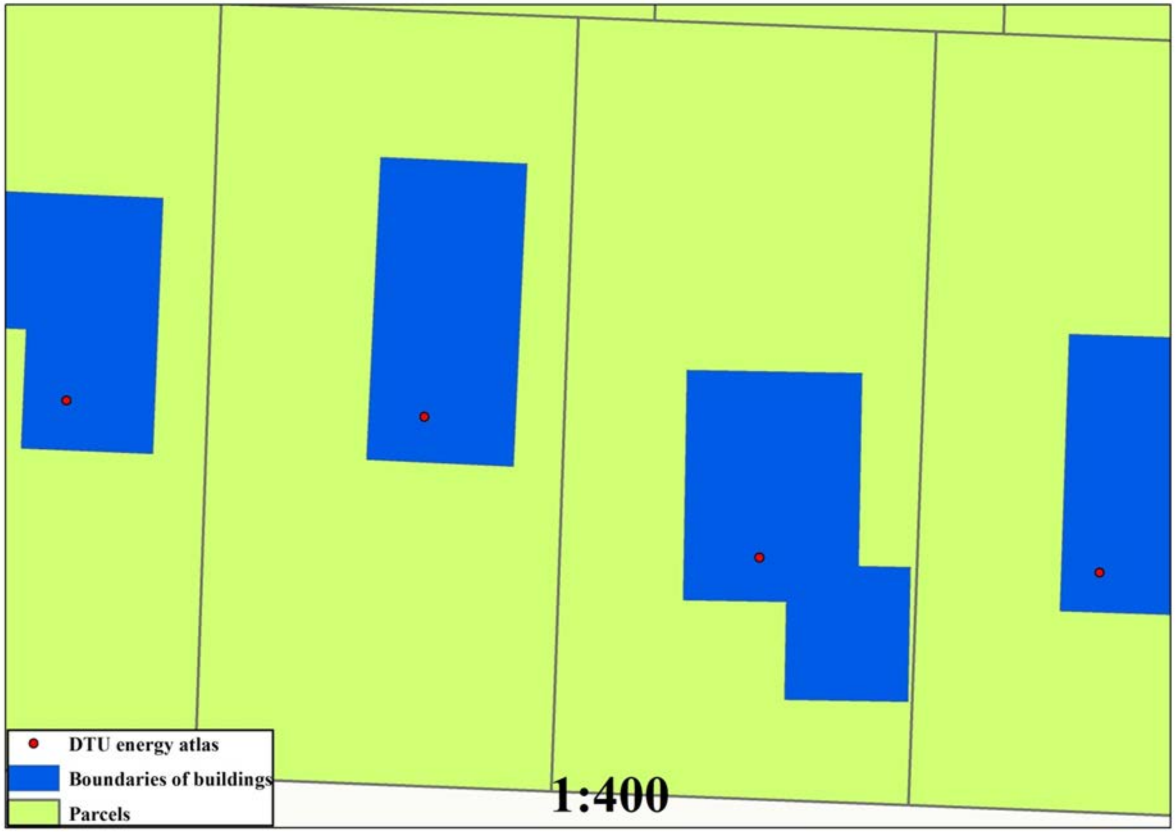
Hourly changes of COPs

Type of heat pump	Region	Seasons				Yearly average
		Spring	Summer	Autumn	Winter	
GSHP	Denmark	3.05	3.95	3.40	2.69	3.27
ASHP	East Denmark	2.72	3.30	2.54	2.02	2.65
ASHP	West Denmark	2.70	3.22	2.47	2.01	2.60

Seasonal COPs

Spatial constraints

- Maybe there is not enough space to install ground source heat pumps



$$COP = \frac{W_h}{W_e} = \frac{W_h}{W_h - W_{gr}} \Rightarrow W_h = \frac{COP}{COP-1} \cdot W_{gr} \Rightarrow W_h = P_{h,spec} \cdot A_{av} \cdot k_{area} \cdot T_{flh} \cdot \frac{COP_{av}}{COP_{av}-1}$$

Spatial constraints - results

- A Heat pump can only supply its own demand, not the neighbours
- Example 1: Heat pump can cover 100 MWh, building's demand is 50 MWh → Heat pump can produce at most 50 MWh
- Example 2: Heat pump can cover 100 MWh, building's demand is 150 MWh → Heat pump can produce at most 100 MWh

Region	Building type	Useable area (km^2)	Heat demand (TWh)
DKE	Single-family	2194	4.8
DKE	Multi-family	37	0.7
DKW	Single-family	6402	6.7
DKW	Multi-family	45	0.3

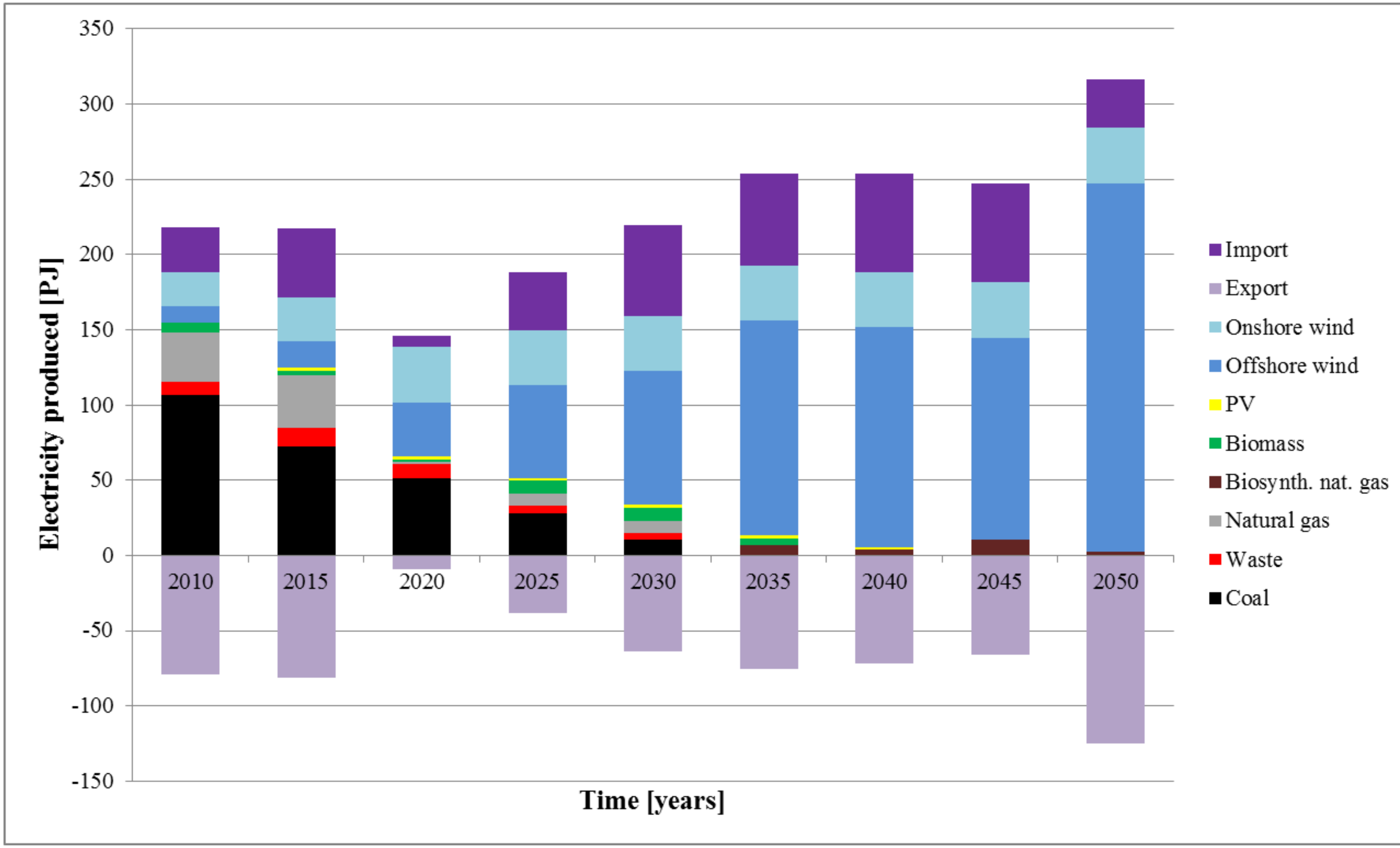
Analysed scenarios

- Base scenario includes politically agreed renewable energy targets declared in :
  - At least 50 % of electricity consumption needs to be produced from wind power starting from 2020.
  - Use of fossil fuels is forbidden in the production of electricity and heat starting from 2035.

- NoIHP (No Installation of Heat Pumps) – The only difference from Base scenario is that installation of residential ASHPs and GSHPs is not allowed.

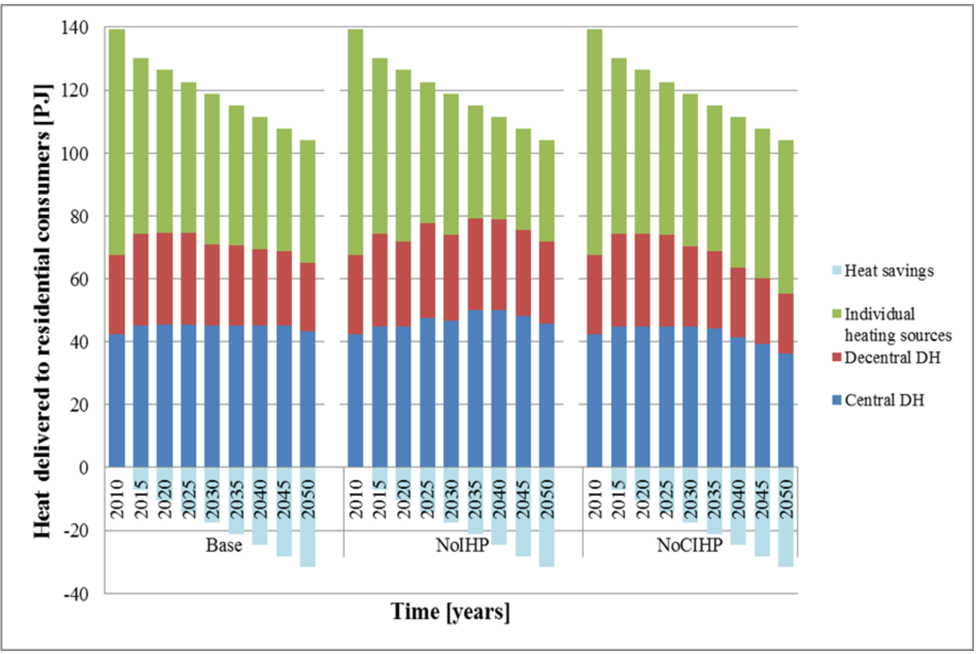
- NoCIHP (No Constrains on Installation of Heat Pumps) – The only difference from Base scenario is that installation of residential GSHPs is unconstrained

Results – Electricity production

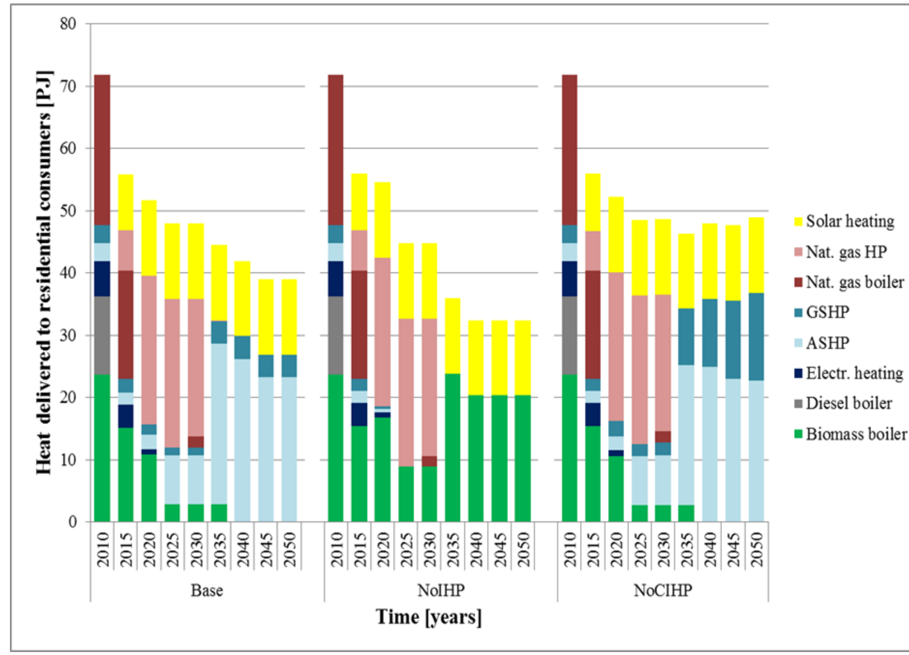


Electricity production divided by fuels

Results – Heat supply

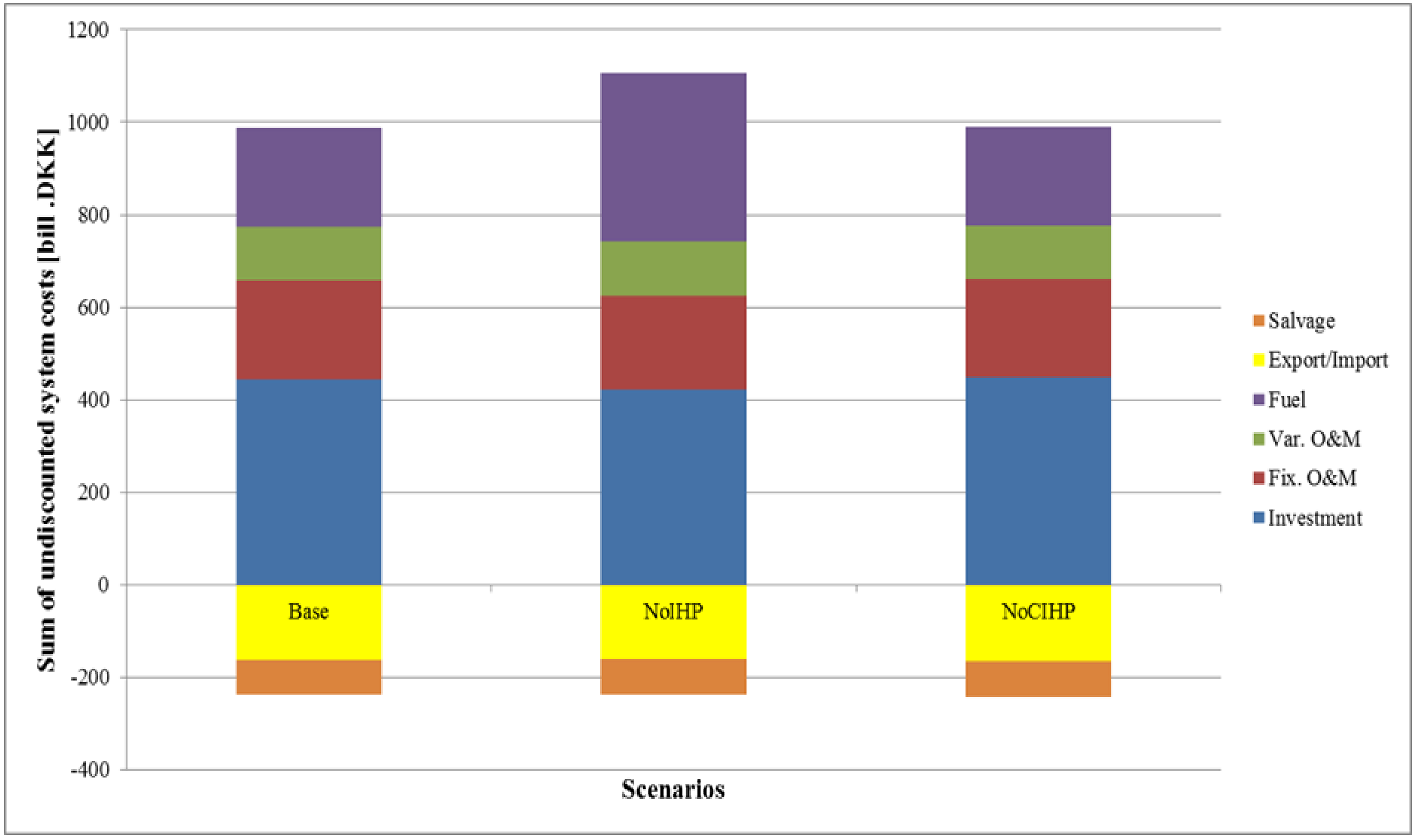


Heat delivered to residential consumers



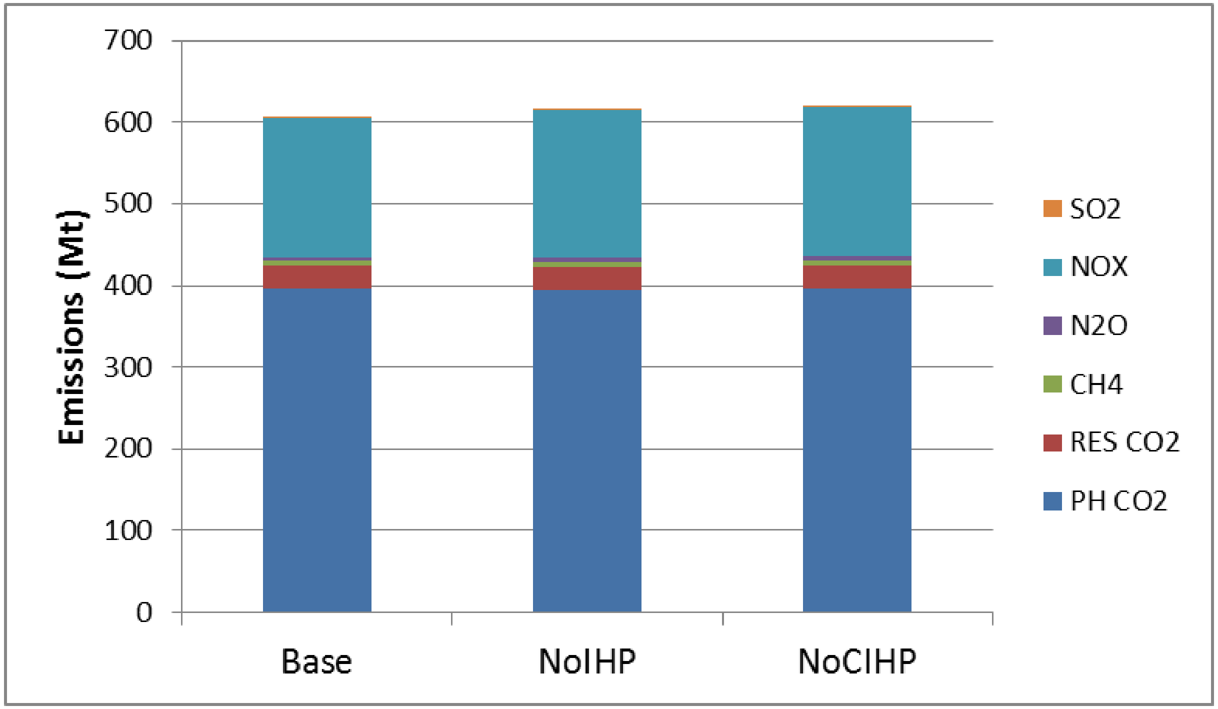
Heat delivered to residential consumers from individual heating sources

Results – total system costs



Sum of total undiscounted system over the analysed period

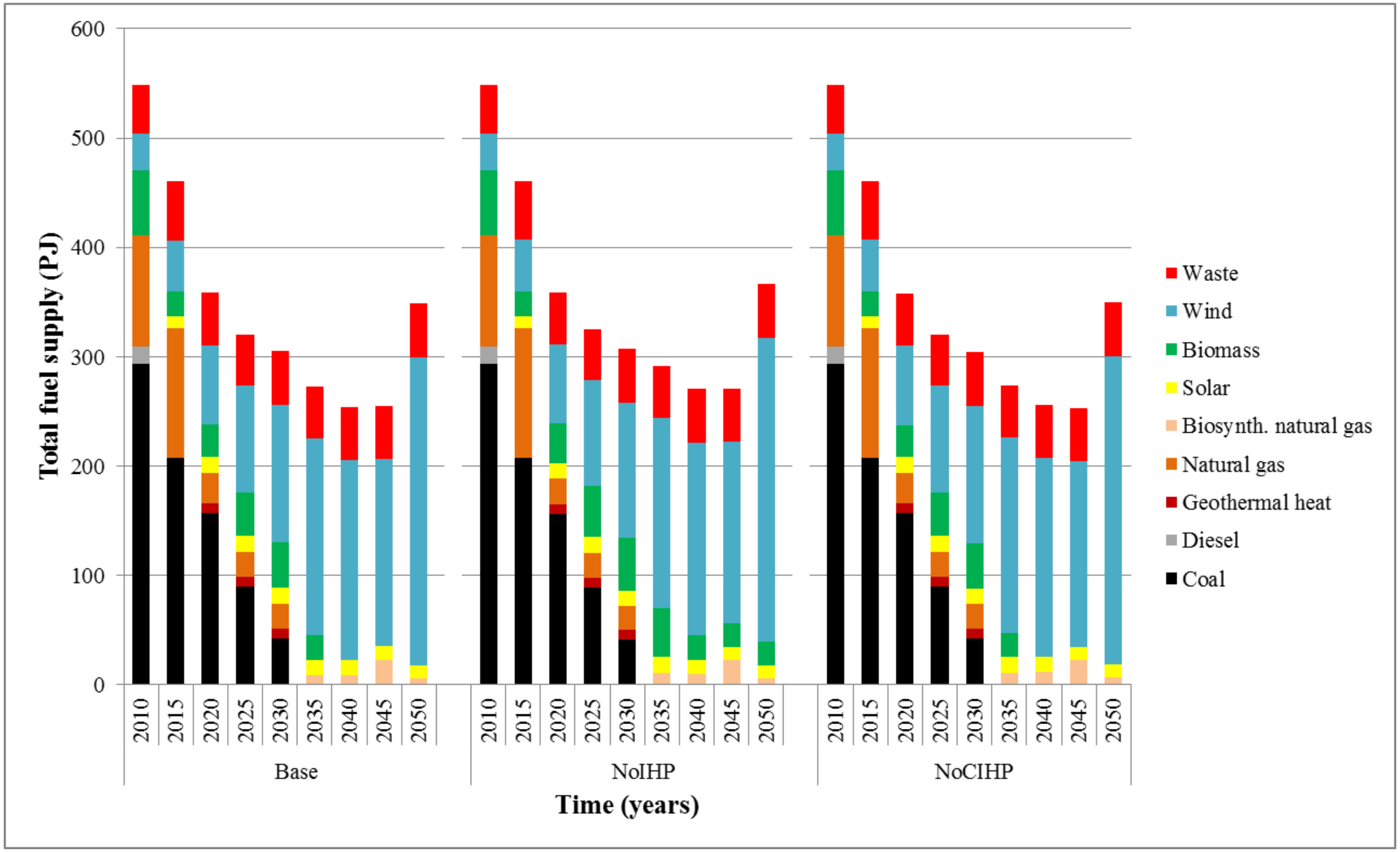
Results – environmental emissions



Sum of total environmental emissions over the analysed period

Small differences among scenarios in emissions

Results – fuel consumption



Sum of total environmental emissions over the analysed period

Small differences among scenarios in fuel consumption

Sensitivity analysis

Sensitivity action	Change of results relative to Base scenario							
	System costs	CO_2 emissions	Onshore wind production	Offshore wind production	DH production	GSHP production	ASHP production	Biomass boilers production
- 10 % investment costs of ASHPs	-0.4%	0.4%	0.0%	-1.8%	-5.4%	-21.7%	38.9%	-22.7%
- 10 % investment costs of GSHPs	-0.1%	0.1%	0.0%	-0.9%	-0.9%	53.2%	2.9%	-13.3%
- 10 % investment costs of wind turbin.	-2.9%	0.3%	0.0%	19.6%	1.2%	8.2%	3.2%	-25.0%
- 10 % price of biomass	-1.1%	-1.6%	0.0%	-3.4%	-3.9%	-23.9%	-15.6%	94.6%
- 20 % price of biomass	-2.5%	-5.5%	0.0%	-7.1%	-14.0%	-41.6%	-39.7%	288.8%
- 20 % inv. costs of DH expansion	-0.2%	0.2%	0.0%	-0.7%	0.9%	-1.5%	-5.4%	2.4%
+ 10 % investment costs of ASHPs	0.2%	-0.4%	0.0%	-1.1%	2.0%	-1.1%	-26.8%	41.8%
+ 10 % investment costs of GSHPs	0.0%	-0.1%	0.0%	-0.2%	0.4%	-54.4%	2.3%	10.4%
+ 10 % investment costs of wind turbin.	2.5%	2.5%	0.0%	-14.0%	-1.0%	-24.1%	-3.2%	29.4%
+ 10 % price of biomass	0.7%	2.2%	0.0%	-0.6%	2.0%	12.5%	0.7%	-33.7%
+ 20 % price of biomass	1.3%	3.9%	0.0%	1.0%	2.5%	8.5%	-0.2%	-36.1%
+ 20 % inv. costs of DH expansion	0.2%	0.0%	0.0%	-0.2%	-1.5%	1.4%	10.2%	-5.9%
reduction factor k_{area} = 0.8	-0.01%	0.0%	0.0%	0.0%	-0.4%	23.0%	-1.5%	-0.5%
Fixed COPs over whole year	-0.2%	-0.3%	0.0%	-2.0%	-1.6%	-1.5%	9.5%	-2.9%
- 50 % out of total heat saving potential	0.1%	0.1%	0.0%	-0.1%	-1.8%	0.2%	12.8%	-8.4%
Forbidding heat savings	8.5%	0.9%	0.0%	3.2%	4.8%	3.9%	82.2%	45.5%

Conclusions and future work

- Improved modelling makes a difference
- Residential HPs produce of 66-70 % of heat from individual heating sources, i.e. 24-28 % of total heat demand after 2035.
- Danish energy system can function without investments in residential HPs - total system costs increase by 16 % and biomass use by 70 %.
- Parameters $P_{h,spec}$ and k_{area} should be explored in more details
- ASHPs in multi-storey buildings – noise as a by-product
- More detailed COPs
- Role of residential HPs in the light of accelerated introduction of heat savings

Thank you for your attention

- Questions
- Answers
- Comments
- Suggestions

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